CHAPTER 4

Development of Production Scheduling Method

4.1 Scheduling Constraints and Objectives

4.1.1 Scheduling Constraints

After analyzing the processes, the constraints in each process for sequencing the orders are established. The major factors for development of a new scheduling method are set up constraints, the product quality, the company policies, and balance workflow in the process line.

1.) The constraints in set up

The constraints in sequencing the orders in each machine affect up the machine. Therefore, set up time can be used to determine the priority in sequencing jobs at the machines.

1.1) In Dyeing machine, the constraint is only the color sequencing in High Temperature and High-Pressure Dyeing Machines (HT) and Rapid Winch Dyeing machine (RW). The color sequencing does not affect the Winch Dyeing machine (W). The colors can be sequenced at random

Dyeing Machine HT, RW	
Constraint	Priority
Color Sequencing	1

Table 4.1.1.1 Dyeing Machine Constraints

1.2) The Finishing machines have quite same constraints but they do not have the same priority in each type of Finishing machine. Factors involved in prioritizing at these machines are:

1.2.1) The type of fabric

The type of fabric affects the temperature of Finishing process, The Cut- Fabric Finishing machine, a lot of time to cool down and warm up in resetting up the temperature for the next order. Therefore, it has a high priority.

1.2.2) Cleaning the roller because of Thermo-migration effect

Some consecutive orders may have Thermo-migrating effect. For example, red, dark brown or dark violet should be followed by dark blue, navy blue or black. Otherwise, the rollers in the machine must be cleaned by running with clean defect fabric to prevent residual color due to Thermo-migration from printing on to the following job. The Cut-Fabric Finishing machine has a lot of Thermo-migration effect problem in its roller because it uses the high temperature for finishing, especially in TK and Poly-fabrics.

1.2.3) The width of fabric

If the consecutive order has different fabric width, the process may have to be stopped for adjustment. However, the Cut Fabric-Finishing machine can be adjusted for the width of fabric easier than the Uncut Fabric-Finishing machine.

1.2.4) Color sequencing

Sequencing of colors may have effects on the consistency of the color of the following jobs. In the Finishing process, the level of darkness of color should be gradual from dark to light or from light to dark. Sequencing of colors in dyeing is much more complicated.

1.2.5) Width-adjusting equipment

Width-adjusting equipment is used in the Gas Finishing machine. It has a range of widths that are suitable for individual orders. If the equipment need to be changed, time will be lost for installing and heating it. The important of the set up constraints are ranked as shown in Table 4.1.1.2 and Table 4.1.2.3

Cut Fabric Finishing Machine	
Constraint	Priority
The type of fabric	1
Thermo-migration effect	2
The width of fabric	3
Color consistency	4

Table 4.1.1.2 Cut Fabric Finishing Machine constraints

Gas Finishing Machine	
Constraint	Priority
Width adjust equipment	1
Thermo-migration effect	2
The width of fabric	3
The type of fabric	4
Color consistency	5

Table 4.1.1.3 Gas Finishing Machine constraints

2.) The quality of the product

The scheduling method relates to the quality of the product in the machine loading and sequencing the order

2.1) Dyeing section

In scheduling method; the quality of the product relate in two factors.

2.1.1) Machine type and capacity

The three types of machine are Rapid Winch, Winch, and High Temperature and High Pressure machines. The jobs must be processed in the suitable type of machine with appropriate capacity. Some order can be produced both in Rapid Winch and Winch more than one type of machines. Rapid-winch machines are better because dyeing conditions can be controlled better. It is preferable to dye on order in one batch for color consistency. A large batch may be splited into small batches only in the Uncut Fabric order, which require lower quality.

2.1.2) Sequencing the colors

Sequencing colors of consecutive orders have effects on consistency of colors of the dyed jobs or cleaning of the machine may be necessary. To process the following order without cleaning the machine, the order must not have any effect from the color formula of the previous job.

2.2) Finishing section

2.2.1) Sequencing the orders

The quality of the product after finishing is that all the fabric in the same group of orders has the same characteristic in width, softness and shrinkage. The

related quality factor in scheduling is that the orders in the same group are processes continuously. The same condition applies for the machines used in chemical, temperature and width setup finishing.

3.) The policies of the company

The related policies for scheduling are as follow

- The rework orders must be processed urgently
- All orders in the same group should be delivered together

4.) Balanced workflow in process line

Due to Dyeing section has higher capacity than Finishing section. The scheduler should plan to have production in Dyeing section that balances to the capacity in each type of Finishing machine. This is to minimize work in process in the finishing. Moreover, the scheduler should balance workload in each group of finishing machine, too.

4.1.2 The Objectives of Scheduling

The objectives in developing of new scheduling method are as follow.

1) Reduce set up time: This objective implies two objectives, namely:
   1.1) Reduce mean flow time
   1.2) Increase machine utilization
2) Reduce work in process
3) Maximize product quality

4.2 Scheduling Strategies

1) Job shop

In the production line flowing from Dyeing to Finishing, it consists of a series of operations, which the fabric will be processed through at each stage, various types of machines with different ranges of capacities are allocated. Each order will go through the specific machine, which is designated. It is not necessary that the order will go through every operation. in the production line. This depends significantly upon the nature of the fabric as well as the required final finishing and quality. Consequently, similar machines of various capacities are grouped together in each station. This will be classified in job

shop production. Thus this study mainly study in the job shop problem and scheduling method.

2) Backward scheduling

Constraints in the Finishing process are found to be of higher magnitude and more complicated than those exist in the Dyeing section. The existing scheduling method uses forward scheduling from dyeing to finishing and schedules these two sections separately. This inevitably causes a lot of sequencing related problems in the Finishing process lines. Time is wasted repeatedly in setting up the machines. A method is therefore developed to plan schedule from the finishing end that has higher constraints and more complexity toward Dyeing section that has lower constraints. This new method uses backward scheduling. Moreover, it is easier to fit the schedule that generated from the Finishing line into the Dyeing production lines due to a greater number of Dyeing machines with wide ranges of capacities

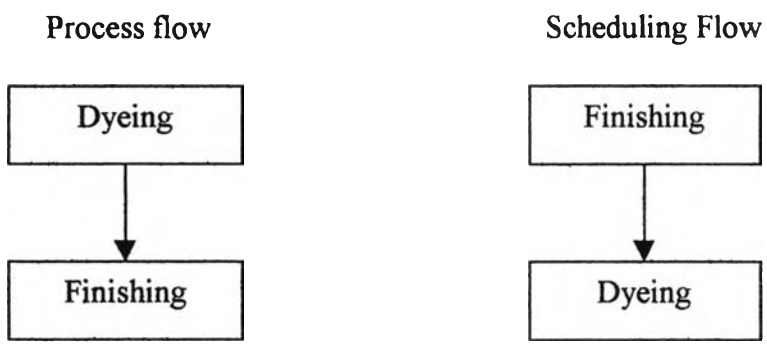


Figure 4.2.1 Backward Scheduling

3) Dynamic rule

The developing method has the time dependent. It arranges orders, which are planned schedule, within a period of time. The length of period depends on the density of orders of different priorities during that time. (If the density of order is high, the period of scheduling is then set short.)

4) Constraint-Guided heuristic search

The scheduling related constraints in Dyeing and Finishing process required certain extent of production knowledge and experiences of the working personnel. For instances, color sequencing controlled scheduling, the characteristic of machine temperature and configuration set up. The developing scheduling method uses the concept of Constraint-Guided heuristic search, that is a knowledge-based approach. The scheduler has to understand these constraints and make rules or heuristic to schedule with them.

5) Group Scheduling[7]

Now that machine set up time can be cost effective, it is desirable if fabrics of the same nature or order are processed under the same production conditions continually. A new method is developed utilizing Group Scheduling to process orders of the same characteristics simultaneously as to reduce set up time. High quality of the final product can also be achieved if orders of similar characteristics are processed under the same production environment. The orders that will be produced in each machine can be group for scheduling as

5.1) Dyeing section[13]

5.1.1) The light and dark color will be grouped separately to enhance color consistency for the production machines as well as to optimize the possibilities that any urgent works or reworks can be inserted quickly.

5.2) Finishing section

5.2.1) Fabrics of similar characteristics that required the same types of finishing will be grouped to be processed continuously as to reduce temperature setting up time.

5.2.2) Fabrics required the same width stretching will be grouped to be processed together as to reduce time required for adjusting machine configuration.

5.2.3) Sub orders of the same main order should be scheduled for processing together in order to maintain the same level of quality.

6) The priority rule

6.1) The Product Priority. A policy has been set that rework order takes the higher priority to be processed urgently against all other orders in the sequence. However

there are also occasions that they are not always the first in line dues to some constraints which should not be overlooked, for instances,

- Times consumed in temperature setting up in some machines such as the Cut Fabric Finishing machine.
- The heuristic of SPT-LPT in Finishing section.

6.2) The Priority of Machine. The major production lines are at the Cut Fabric Finishing Machines and Gas Finishing Machines. Thus the scheduler gives the first priority to these two production lines more than other machines such as Steam Finishing Machine.

7) Dispatching rule[17]

7.1) SPT-LPT (Shortest Processing Time-Longest – Processing Time)

This developing scheduling method is characterized as the backward scheduling that planning starts in Finishing process towards Dyeing process. For instance, order that has short Dyeing processing time but long Finishing processing time will be scheduled at the head of the sequence. This is to ensure that Finishing machines do not remain idle for long period of time. This concept is applied from SPT-LPT in dispatching rule. This method separates orders into two groups which are G1 and G2.

G1: The orders of Finishing commission, Rework for only the single order and the groups of orders with the same color in bleaching, off white and scouring.

G2: The orders of Dyeing and Finishing commission except the single order and the groups of orders with the same color in bleaching, off white and scouring.

7.2) FCFS (First Come First Served)

In Drying section and Cutting section, no constraint in sequencing. FCFS is therefore used to sequence orders from the ex-machines.

8) Work load balancing

In Dyeing section, it has higher capacity than Finishing section. It needs to balance workflow for minimize work-in-process. Moreover, it needs to balance workload in Finishing section to reduce production lead-time by producing as earlies as it can.

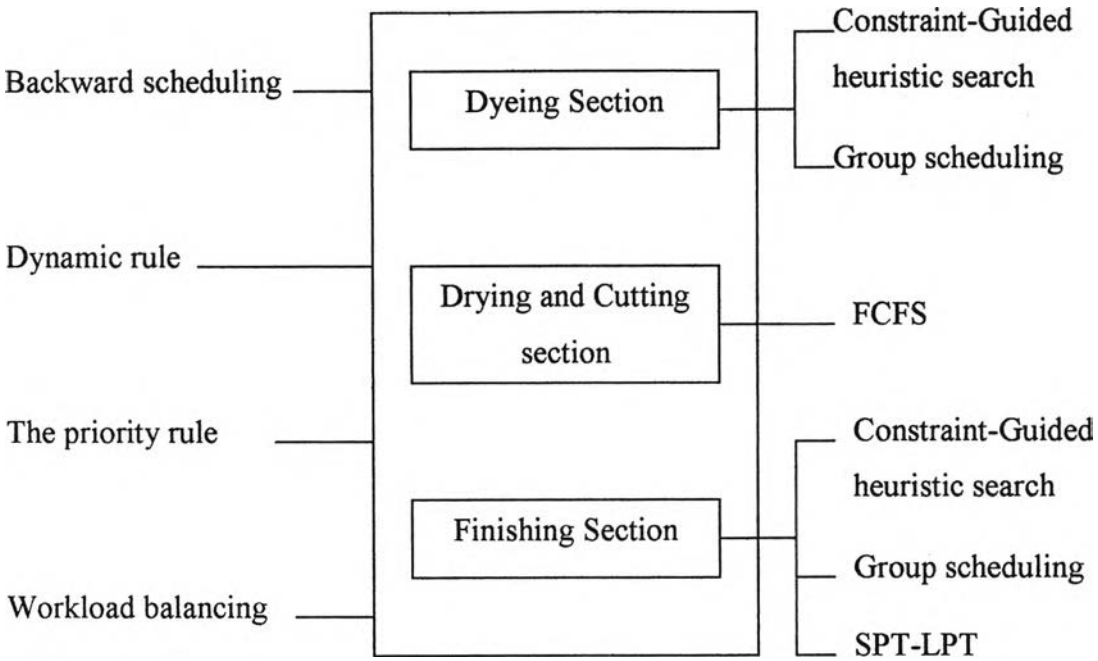


Figure 4.2.2 The main concept in developed method

4.3 Procedure for Developing Schedules

The procedure of developing scheduling consists of three phases:[30]

1) The machine allocation phase
2) The sequencing phase
3) The release timing phase

1) The machine allocation phase

The machine allocation phase assigns each order to a particular machine or group of machines. The schedule in this phase starts in the Finishing section and then in the Dyeing section. The machine allocation phase in each section will be completed before sequencing and timing in that phase. The concept in allocation in each section depends on the constraint in that machine such as:

1.1) The relevant machine allocation constraints in Cut Fabric Finishing machine.

1.1.1) The type of fabric: This implies grouping of works accordingly to the required finishing temperature

1.2) Other constraints related to machine allocation in Gas Finishing machine

1.2.1) The width of fabric: This implies the size of Width adjusting equipment.

1.3) The related constraint of machine allocation in Dyeing machine

1.3.1) The type of fabric

1.3.2) The type of dyeing

1.3.3) The weight of fabric

2) The sequencing phase

The main constraint of sequencing phase in Dyeing section is controlling color sequencing in order to reduce machine set up time. The machines, that are color independent will employ the concept of FCFS. The Drying and Cutting section, where machines are not bound by any particular constraint, FCFS heuristic is also applied. In Finishing section, the main constraint controlling sequencing is color consistency and the required final finishing of the fabric Moreover, the Finishing section must also consider the priority of rework fabric, too.

3) The release timing phase

The release timing phase is the last phase of scheduling. The scheduler calculates the real time to release each order in the sequence form the processing time and the release time of each machine. In Dyeing section, at each machine the orders are processed related to the time that the orders have to process in Finishing machine. In drying and Cutting section, the orders are processed in which they arrive and processing start as soon as the order is available. In Finishing section, the release time is considered from the maximum lateness in each machine. Then the orders before and after the maximum lateness order will be modified from the time of the maximum lateness order.

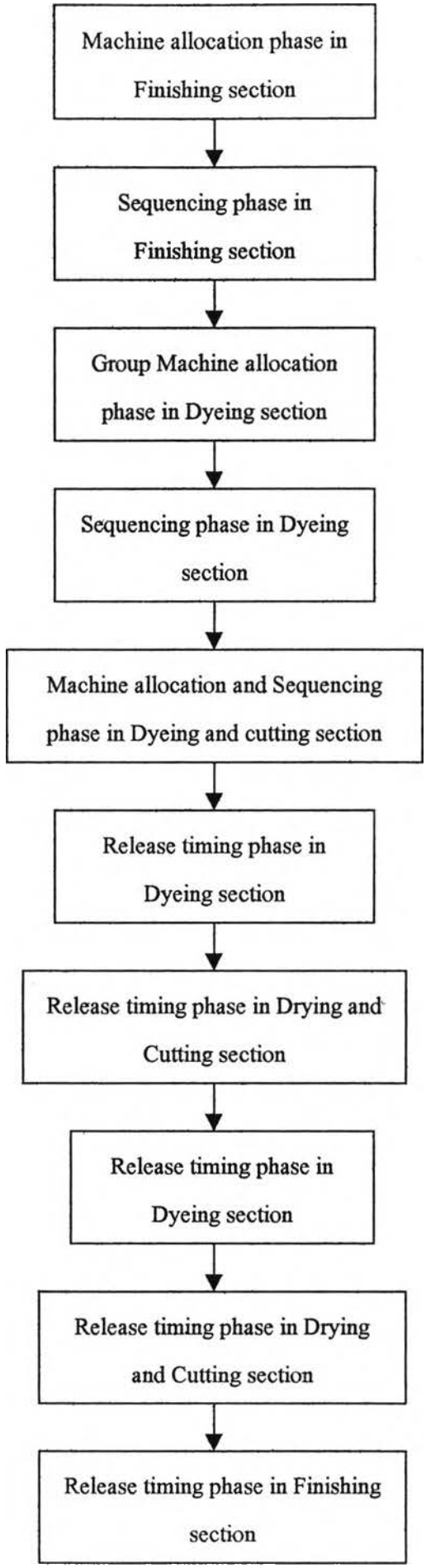


Figure 4.3 The scheduling phases

4.4 Work Procedure for the newly Developed Scheduling System

Step 1. Enter details of orders.

Data to be entered are:

- The date that the fabric is sent to the company
- The date that the lab number is confirm
- The type of production
    1. Dyeing and Finishing Commission
    2. Finishing Commission
    3. Rework in Dyeing
    4. Rework in Finishing
- The type of fabric: this depends on the yarn of fabric such as Nylon, CVC, Cotton
- The part of fabric
    - Fabric
    - Rip
    - Collar
    - Sleeve
- Lab number
- Color
- The weight g/m^2 or g/yard
- The width (inch)
- The weight (kg)
- The amount of roll (Unit)
- Customer name
- Order Number
- The type of finishing
    - Cut fabric finishing
    - Uncut fabric finishing

Step 2. Enter details of production.

Data to be entered are:

- The amount of machine in each type
- Due date
- The accepted excess or shortage time comparing with the mean processing time of each Finishing machine (X_i)

Step 3. Set the period of scheduling

Set the period of scheduling by selecting the first date and the last date. Then, the scheduler will select and process only the ready orders in that period. The ready order is the order that the fabric has been sent to the company and the LAB number confirmed.

Example 3

The period of scheduling 1/6/99 - 2/6/99

Set fabric date	Ok lab date	
1/6/99	1/6/99	Ready
1/6/99	5/6/99	Not Ready
1/6/99	2/6/99	Ready
3/6/99	4/6/99	Not Ready

Step 4. Classify the type of finishing

Classify the ready orders of step 3 to the type of Finishing machine

1.) Cut Fabric Finishing machines are used for Cut Fabric Finishing orders.

2.) Steam Finishing machines are used for the cotton fabric in Uncut Fabric Finishing orders.

3.) Gas Finishing machines are used for all fabric in Uncut Fabric Finishing orders except cotton fabric.

For the scheduling of the Finishing machines, it is imperative that the same groups of orders must be scheduled to be processed continuously to attain the same condition of production. This results in good quality Finishing product. The same group of orders are identified from

- Customer name
- The type of fabric
- The weight g/m^2
- The width
- The type of Finishing
- (Order number can be the same number or different number)

The schedules can be classified into three types of orders

1.) The single order

Example 4.1

Customer	Order No.	Type of fabric	Weight g/m^2 or g/yard	Width (inches)	Type of Finishing	Color	
A	0001	Poly	230	65	Uncut	Red	→ A single order
B	1000	Nylon	155	84	Uncut	Black	→ A single order

2.) The group of orders with the same color

Example 4.2

Customer	Order No.	Type of fabric	Weight g/m^2 or g/yard	Width (inches)	Type of Finishing	Color	
A	0001	Poly	230	65	Uncut	White	} A group of order with the same color
A	0002	Poly	230	65	Uncut	White	
A	0003	Poly	230	65	Uncut	White	

3.) The group of orders with different colors

Example 4.3

Customer	Order No.	Type of fabric	Weight g/m^2 or g/yard	Width (inches)	Type of Finishing	Color	
A	0001	Poly	230	65	Uncut	White	} A group of order with different color
A	0002	Poly	230	65	Uncut	Red	
A	0003	Poly	230	65	Uncut	Black	

Step 5. Sequence the orders in Cut Fabric Finishing machines and Gas Finishing machines

Step 5.1. Sequence the order in Cut Fabric Finishing machines.

5.1.1 Group the orders for the same temperature of Finishing process

Temperature	Type of Fabric
150 °C	CVC, Cotton in light and medium color
160 °C	Cotton in dark color, TR, TC
165 °C	TK, Poly, Nylon

5.1.2 Sum of processing time of order for each group of temperature

$$W_{it} = \sum_{n_{1t}=1}^{n_{1t}} P_{1t}$$

Unit	Temperature	Sum of Processing time $\sum_{n_{it}=1}^{n_{it}} P_{it}$ (minutes)
W_{11}	150 °C	2503.8
W_{12}	160 °C	823.8
W_{13}	165 °C	1200

5.1.3 Calculate the mean processing time per machine $(\overline{W_i})$

$$Mean\ peoces\sin g\ time\ per\ machine\ (\overline{W_i}) = \frac{Sum\ of\ proces\sin g\ time\ of\ all\ order\ \left(\sum_{ni=1}^{ni} P_{in}\right)}{Number\ of\ machine\ (N_i)}$$

$$\overline{W_1} = \frac{\sum_{n1=1}^{n1} P_{1n}}{N_1} = \frac{\sum_{t=1}^{3} W_{1t}}{N_1}$$

5.1.4 Choose the group of orders with the same temperature having the highest Sum of processing time to be allocated to an available Cut Fabric Finishing machines. Then if there are more Cut Fabric Finishing machine available, the next group of orders with second largest Sum of the processing time shall be processed. This procedure will be followed until no Cut Fabric Finishing machine is available. These selected groups of orders with the same temperature will be the main orders in each machine.

Example 5.1.4

The scheduler has 2 available Cut Fabric Finishing machines. From the table in 5.1.2, he will also choose 2 groups of order with the same temperature as W_{11} = 2503.8 Min and W_{13} = 1200 Min.

5.1.5 Classify the group of orders with the same temperature to be separated and then combined with the other group.

5.1.5.1 $\left|W_{1t} - \overline{W_1}\right| \leq X_1$: If the sum of the process time of selected group of orders with the same temperature (W_{it}) is not different from the mean processing time per machine $(\overline{W_1})$ by more than the accepted excess or shortage time of the machine (X_i).,or machine will process all orders in that group of temperature.

Example 5.1.5.1

$W_{1t} = 2240, \quad \overline{W_1} = 2200.45, \quad X_1 = 90$

$$\left|W_{1t} - \overline{W_1}\right| \leq X_1$$

$$\left|2240 - 2200.45\right| \leq 90$$

$$39.55 \leq 90$$

5.1.5.2 $W_{1t} - \overline{W_1} > X_1$: If the sum of the processing time of selected group of orders will the same temperature (W_{it}) is different from the mean processing time per machine $(\overline{W_1})$ by more than the accepted excess or shortage

time of the machine (X_i). Some orders in that group have to be separated to the other machines approximately equal the amount of excess.

Example 5.1.5.2

$W_{1t} = 2503.8, \quad \overline{W_1} = 2200.45, \quad X_1 = 90$

$$W_{1t} - \overline{W_1} > X_1$$

$$2503.8 - 2200.45 > 90$$

$$303.35 > 90$$

5.1.5.3 $\overline{W_1} - W_{1t} > X_1$: If the sum of the processing time of selected groups of orders with the same temperature (W_{it}) is lower than the mean processing time per machine $(\overline{W_1})$ more than the accepted excess or shortage time of the machine (X_i). These orders in this selected group have to be combined with the order in unselected group of temperature in order to create the sum of processing time of all orders approximately equal the mean processing time per machine.

Example 5.1.5.3

$W_{1t} = 1200, \quad \overline{W_1} = 2200.45, \quad X_1 = 90$

$$\overline{W_1} - W_{1t} > X_1$$

$$2200.45 - 1200 > 90$$

$$100.45 > 90$$

5.1.6 Separate the excess orders and allocate these separated orders to each available machine

5.1.6.1 The orders in the groups of the same temperature that have to be separated due to the steps in 5.1.5.2 and 5.1.5.3 must be classified into two groups of orders as

G1: The orders of Finishing commission, Rework for only the single order and the groups of orders with the same color in bleaching, off white and scouring.

G2: The orders of Dyeing and Finishing commission except the single order and the groups of orders with the same color in bleaching, off white and scouring.

5.1.6.2 The orders in G1 of different groups of temperature are grouped together with the same width of fabric. The same width of fabric in Cut Fabric Finishing order means that the orders have the different of width not more than 2 inches. G2 is also classified the same way.

The same groups of width: $|w_n - w_{n+1}| \leq 2$

Example 5.1.6.2

The same group of width

Z	Order No.	Width of fabric w_n (inches)	$w_n - w_{n+1}$ (inches)
1	001	70	-
2	002	72	2
3	003	72	0
4	004	74	2
5	005	74	0

5.1.6.3 Sum of processing time in each group of width in G1 and G2 in the separating group of temperature.

Example 5.1.6.3

The separating group of temperature in 150 °C

G1	
Group of width	Sum of processing time (min.)
65-68	970.8
84-86	316.8
78-80	171.6
60-62	136.8
72	64.2

G2	
Group of width	Sum of processing time (min.)
68	265.2
53	225.6
69	195
72-74	142.2
84	124.8
60-62	62.4
88	7.8

5.1.6.4 In the separating group, choose the group of width that have the sum of processing time nearly equal the excess in 5.1.5.2 (Scheduler can select more than one group). Moreover, the scheduler must select the orders from G1 first and then select from G2

Example 5.1.6.4

From the table in 5.1.6.3 and the excess is about 250 minutes. The scheduler selects the group of width in 78-80 and 72 in G1 that sum of processing time are 235.8 minutes.

5.1.6.5 The machines are allocated for the orders in the case of 5.1.5.1 or 5.1.5.2 first. The remaining machines are available for the main orders of selected groups of temperature in 5.1.4. The scheduler calculates the difference in processing time between the sum of processing time of the orders in the remaining machines and the mean processing time per machine $(\overline{W_1})$. Then the scheduler selects the separated orders from each groups of temperature in 5.1.6.4 that show the processing time close to this difference. In this step all orders are allocated to each machine.

Example 5.1.6.5

$\overline{W_1}$ = 2200.45 Min

Sum of processing time in the remaining machines

Machine 1 = 1500 Min Machine 2 = 1700 Min

The separated orders in each groups of temperature

Group 1 = 700 Min Group 2 = 500 Min

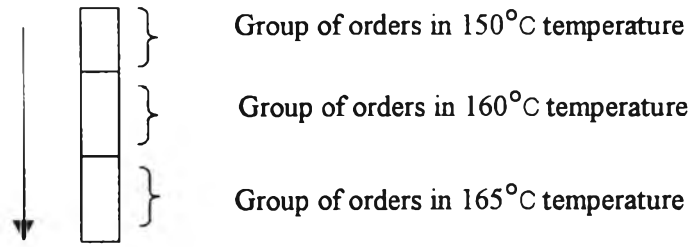
Thus,

Machine 1 will choose Group 1 and the processing time is 2200 minutes.

Machine 2 will choose Group 2 and the processing time is 2200 minutes.

5.1.7 In each machine, the sequence must be sequenced from the low temperature (150 °C) to high temperature (165 °C)

Example 5.1.7



5.1.8 In each machine the orders in each group of temperature are classified into G1 and G2, and group the same width of the fabric in G1 or G2

5.1.9 Sequencing the order according to the sequencing rule in Finishing machine. This step needs the flow supervisor to adjust the sequence of color.

Step 5.2. Sequence the orders in Gas Finishing machines

5.2.1 Separate the orders of Rib, Collar, and Sleeve from this Step of scheduling.

5.2.2 Calculate the mean processing time per machine $(\overline{W_i})$

$$\overline{W_2} = \frac{\sum_{n2=1}^{n2} P_{2n}}{N_2 - 1}$$

From (N_2 - 1), a machine will be used for the Rib, Collar, Sleeve and inside rework orders.

5.2.3 Group the orders according to the width of fabric and classify the group of width that some orders must be separated some orders to combine with the other group.

5.2.3.1 Group the orders that have the width of more than 41 inches (w > 41") and sum the processing time (W_{2w})

5.2.3.1.1 $\left|W_{21} - \overline{W_2}\right| \leq X_2$ A machine will process all orders in this groups

5.2.3.1.2 $W_{21} - \overline{W_2} > X_2$ Some orders in that group have to be separated to be processed by other machines considering the quantity of excess

5.2.3.1.3 $\overline{W_2} - W_{21} > X_2$ All orders in this group have to combine with the other groups.

5.2.3.2 Group the orders that have the width ranged between 21 inches and not more than 28 inches ($21 \leq w < 28$) and sum the processing time.

5.2.3.2.1 $\left|W_{22} - \overline{W_2}\right| \leq X_2$ A machine will process all orders in this groups

5.2.3.2.2 $W_{22} - \overline{W_2} > X_2$ Some orders, which have the width between 21 inches to 25 inches ($21 \leq w \leq 25$), in that group have to be separated to be processed by the other machines as much as possible but not more than the excess.

5.2.3.2.3 $\overline{W_2} - W_{22} > X_2$ All orders in this group have to combine with the other groups.

5.2.3.3 Group the orders that have the width between 28 inches to 41 inches ($28 \leq w \leq 41$) and group the same type of fabric and sum the processing time in each type of fabric.

5.2.3.3.1 $\left|W_{24} - \overline{W_2}\right| \leq X_2$ A machine will process all orders in this groups

5.2.3.3.2 $W_{24} - \overline{W_2} > X_2$ Some orders in these groups have to be separated to be processed by the other considering the quantity of excess.

5.2.3.3.3 $\overline{W_2} - W_{24} > X_2$ All orders in this group have to combine with the other groups.

5.2.4 Separate the excess order and allocate the orders to each machine.

5.2.4.1 The orders in the groups of width, that their orders have to be separated due to the step in 5.2.3.1.2, 5.2.3.2.2 and 5.2.3.3.2, must be classified into two groups of order G1 and G2. If the order in G1 can be

separated in the low quantity, the scheduler just group orders in the same width of fabric.

5.2.4.2 Each group of G1 and G2 in separating groups of width, is grouped with the same width of fabric. The same width of fabric in Uncut Fabric Finishing order means that the orders have the same size of width.

Example 5.2.4.2

Order No.	Width of fabric	
001	36	The same width of fabric
002	36	
003	36	
004	40	The same width of fabric
005	40	

5.2.4.3 Sum of processing time in each group of width in G1 and G2

Example 5.2.4.3

The separating group of width is $28 \leq w \leq 41$ of TK fabric

G1	
Group of width	Sum of processing time
38	79
36	39

G2	
Group of width	Sum of processing time
36	1170
37	390
38	694.2
39	156

5.2.4.4 In the separating group of width, choose the groups of width that have the sum of processing time approximately equal the excess. (Scheduler can select more than one group). Moreover the scheduler must select the orders from G1 first and then from G2

Example 5.2.4.4

From the table in Example 5.2.4.3 and the excess is about 426.55 Min. The scheduler selects the groups of width in 38" from G1 and 37" in G2 that sum of processing time is 469 minutes.

5.2.4.5 The machines are allocated for the orders in the case of 5.2.3.1.1, 5.2.3.1.2, 5.2.3.2.1, 5.2.3.2.2, 5.2.3.3.1 and 5.2.3.3.2 first. Then the scheduler allocates the remaining orders to the remaining machines provided that each machine would have the sum of approximately equal to $\overline{W}_2$. The same group of width should be allocated for the same machine. In this step all orders are allocated to each machine.

Example 5.2.4.5

$\overline{W}_2 = 2039.25$

There are two remaining machines: M1 and M2

The remaining orders.

The group of width	The type of fabric	Processing time
$21 \leq w < 28$	All	1320.2
$w > 41$	All	480.95
$28 \leq w \leq 41$	TR	786.5
	Poly	765
	CVC	61.2
	TK	487.95
	TC	203.75

M1 consists group of $21 \leq w < 28$, $w > 41$ and $28 \leq w \leq 41$ in TC. Sum of processing time in M1 = 2004.9

M2 consists group of $21 \leq w < 28$ in TR, Poly, CVC and TK. Sum of processing time in M2 = 2100.65

5.2.5 In each machine the order are classified as G1 and G2, and group the same width of the fabric in G1 or G2. If the order in G1 can be separated in the low quantity, the scheduler just group orders in the same width of fabric.

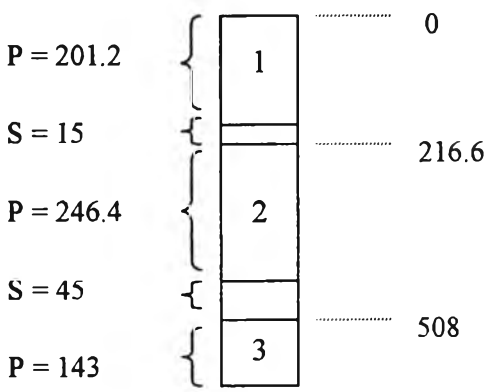
5.2.6 Sequencing the order according to the sequencing rule in Finishing machine. This step needs the floor supervisor to adjust the sequence of color.

Step 6. Calculate the reference release time for each Cut Fabric Finishing machine and Gas Finishing machine

Calculate the reference release time for processing each order in each Finishing machine. Set the first release time equal to zero.

The reference release time of an order in a Finishing machine (TF) = the release time of previous order (TF_{n-1}) + Processing time of previous order (P_{n-1}) + Setup time between these two orders (S_{n-1})

Example 6.1



Step 7. Classify Dyeing Orders

Classify the orders that are processed in Dyeing section

7.1 Separate the orders of finishing commission and rework in Finishing.

7.2 Combine the orders that have the same fabric and the same LAB number.

Step 8. Allocate the orders to the group of Dyeing machine

Classify all the orders into suitable type and capacity to the group of Dyeing machine

Step 9. Classify the orders into three groups of color

Classify the orders for the Dyeing machine in three groups of color namely light color, medium color and dark color. This separating groups of color is used to classify the processing time and has effect in color sequencing in HT and RW.

Step 10. Sequence the orders of each group of Dyeing machine

Sequenced the orders in each group of machine according to the sequencing rule in Dyeing machine. In the sequencing of HT machines and RW machines, the color sequencing is considered, but in winch the color can be sequenced randomly. The same color orders are continuously sequenced from earliest reference release time (TF) from step 6 respectively. The orders for Steam Finishing machine are sequenced last for each color. They assume to have the largest reference release time.

Example 10.1

The order in Steam finishing machine ←

Order	Color	TF
001	White	600
002	White	300
003	White	-
004	White	1200

→

Order	Color	TF
002	White	300
001	White	600
004	White	1200
003	White	-

Step 11. Separate the orders into group of medium color

The orders in the group of HT and RW machines have to classify the colors into group of medium color namely light color and dark color.

11.1 If the medium color has the same color only in the group of light color, combine all the orders and sequence from shortest reference release time.

Example 11.1

Group	Order	Color	TF
Light	001	Blue	300
	002	Blue	600
	003	Blue	1200
Medium	004	Blue	500
	005	Blue	1000

→

Order	Color	TF
001	Blue	300
004	Blue	500
002	Blue	600
005	Blue	1000
003	Blue	1200

11.2 If the medium color has the same color only in the group of dark color, sequence the medium colors before the same dark color.

Example 11.2

Group	Order	Color	TF
Medium	001	Red	1200
Dark	002	Red	700
	003	Red	1000

→

Order	Color	TF
001	Red	1200
002	Red	700
003	Red	1000

11.3 If the medium color has the same color to color in the group of light and dark color, the position of the medium color is sequenced according to 11.1 and 11.2. Then the differences of TF in both positions with the one in front of it in light color and with the other next to it in dark color are compared. The scheduler selects the lower difference.

Example 11.3

Group	Order	Color	TF
Light	001	White	200
	002	Yellow	700
Medium	003	Yellow	800
Dark	004	Yellow	1500

Determine the differences of TF

Yellow (003) – Yellow (002) = 800 – 700

= 100

Yellow (004) – Yellow (003) = 1500 – 800

= 700

100 < 700; So choose the group of light color

↓

Group	Order	Color	TF
Light	001	White	200
	002	Yellow	700
	003	Yellow	800
Medium	004	Yellow	1500

11.4 If the medium color has color different to color in the groups of light and dark color, the difference of reference release time when the medium color is sequenced next to the last order in light color is determined. Another case is when medium color is sequenced in front of the first order in dark color, the difference of

reference release time in these two orders is calculated. The scheduler selects the lower difference. After this step, each machine must have only two groups of order as light and dark.

Example 11.4

Group	Order	Color	TF
Light	001	White	900
	002	Yellow	1700
Medium	003	Gray	1300
Dark	004	Navy blue	700
	005	Yellow	1100

Determine the difference of TF

Yellow (002) – Yellow (003) = 1700 – 1300

= 400

Yellow (003) – Yellow (004) = 1300 – 700

= 600

400 < 600; So choose the group of light color

Group	Order	Color	TF
Light	001	White	900
	002	Yellow	1700
	003	Gray	1300
Dark	004	Navy blue	700
	005	Yellow	1100

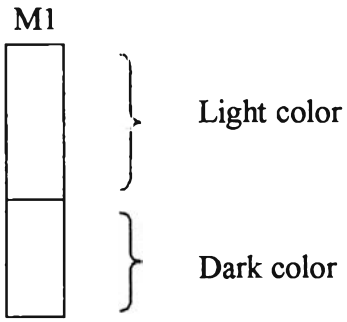
<u>Step 12.</u> Allocate the orders to each Dyeing machine

In step 5, the schedule classifies the orders into their group of machine by considering in type and capacity of machine. In this step, the schedule will allocate the orders to each machine.

12.1 N = 1: If the considered group of machine has only one machine, the sequences are from the group of light color to dark color.

Example 12.1

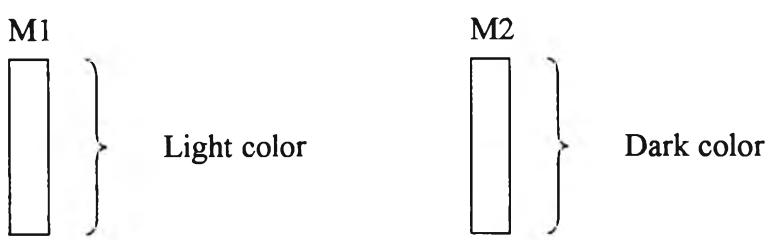
There is only one machine in this group (N = 1)



12.2 N = 2: The group of machine has only two machines. One machine is for the light color and the another is for dark color.

Example 12.2

There are only two machines in this group (N = 2)



12.3 N > 2: The group of machine has more that two machines.

12.3.1 Allocate the order as if there are only two machines as in 12.2 and determine which machine has maximum reference lateness (L'max). The reference lateness (L') will happen when an order, which the reference arrival time in finishing (TA) can not meet the reference release time in finishing (TF).

The reference arrival time in finishing (TA) = The reference Finishing time in Dyeing (F'_D) + The processing time in Dyeing and/or Cutting processes (Pd)

Thus the case of lateness of an order is expressed as.

$$TA > TF$$

And reference lateness (L') = $TA - TF$

$= F'_D + Pd - TF$

Example 12.3.1

Machine 1: The group of light color

Order	The type of fabric	Color	P_D (min.)	F'_D (min.)	Pd (min.)	TA (F'_D + Pd) (min.)	TF (min.)	L' (TA – TF) (min.)
001	Cotton	White	240	240	35	275	439.2	-
002	Cotton	White	240	480	35	515	568.8	-
003	Poly	White	240	720	45	765	1169.4	-
004	TC	Pink	660	1380	45	1425	1056.6	368.4
005	Cotton	Blue	300	1680	35	1715	1093.8	621.2
006	Cotton	Green	300	1980	45	2025	2101.2	-
007	TC	Violet	660	2700	50	2750	790.2	1958.8

Machine 2: The group of dark color

Order	The type of fabric	Color	P_D (mins.)	F'_D (mins.)	Pd (mins.)	TA (F'_D + Pd) (mins.)	TF (mins.)	L' (TA – TF) (mins.)
008	TK	Gray	360	360	60	420	1654.8	-
009	Poly	Red	360	720	55	775	1577.3	-
010	TK	Navy blue	360	1080	50	1130	633	497
011	CVC	Navy blue	840	1920	55	1975	817.2	1157.8
012	CVC	Navy blue	840	2760	30	2790	985.2	1804.8
013	TK	Navy blue	360	3120	35	3155	1397.4	1757.6
014	CVC	Navy blue	840	3960	45	4005	2241.6	1763.4

12.3.2 Add a machine for the group of orders, which has the maximum reference lateness, and relocate the group of orders, which has a new machine.

12.3.2.1 The method for relocation

Try to allocate the orders in machine N first

1.) If in machine N, an order has TA > TF and in machine N+1, an order has TA > TF, allocate the order to machine N+1

2.) If in machine N and machine N+1, an order has TA < TF, allocate the order to the machine, which can process faster.

Example 12.3.2.1

Order	Type of Fabric	Color	P_D	Machine 1					Machine 2				
				F'_D	Pd	TA	TF	L'	F'_D	Pd	TA	TF	L'
001	Cotton	White	240	240	35	275	439.2	-					
002	Cotton	White	240	480	35	515	568.8	-					
003	Poly	White	240	720	45	765	1169.4	-					
004	TC	Pink	160						660	45	705	1056.6	-
005	Cotton	Blue	100	1020	35	1055	1093.8	-					
006	Cotton	Green	300	1320	45	1365	2101.2	-					
007	TC	Violet	660						1320	50	1370	790.2	579.8

12.3.2.2 If there are no more machine or all orders have TA < TF, go to Step 13

If there are remaining machines, go back to Step 12.3.2

After this step, all orders must have the exact sequence in their machines

<u>Step 13.</u> Calculate release time in each order in dyeing

13.1 Calculate the Finishing time and release time in dyeing due to the reference release time in finishing (F_D)

$F_D = TF - Pd$ and $T_D = F_D - P_D$

13.2 Calculate the reference release time in dyeing (TD) according to each case. In each machine, the scheduler calculates the release time from the last order of the sequence to the first order.

1.) If $F_{Dn} > F'_{Dn}$, and $F_{Dn} < T_{Dn+1}$ or it is the last order of the sequence

$TD = F_{Dn} - P_{Dn}$

2.) If $F_{Dn} > F'_{Dn}$ and $F_{Dn} \geq T_{Dn+1}$

$TD = T_{Dn+1} - P_{Dn}$

3.) If $F_{Dn} < F'_{Dn}$

$TD = F'_{Dn} - P_D$

13.3 Calculate the real release time (t) by setting the real time that each machine can start to release the orders. In each machine, the scheduler will calculate from the first order in the sequence and this order will release with real starting time.

Real release time (t_n) = t_{n-1} + (T_{Dn} – T_{Dn-1})

Example 13.3

The real starting time is 8.00 am.

TD_1 = 0	8.00	t_1 = 8.00
TD_2 = 360 min.	8.00 + (360-0)	t_2 = 14.00
TD_3 = 720 min.	14.00 + (720-360)	t_3 = 20.00

Step 14. Sequence and calculate the release time of the orders in Drying and Cutting Section

Sequencing the orders in Drying and Cutting section by using FCFS heuristic, and calculate the release time and Finishing time of each order in each machine.

The Finishing time (f_n) = the release time (t_n) + Processing time (P_n)

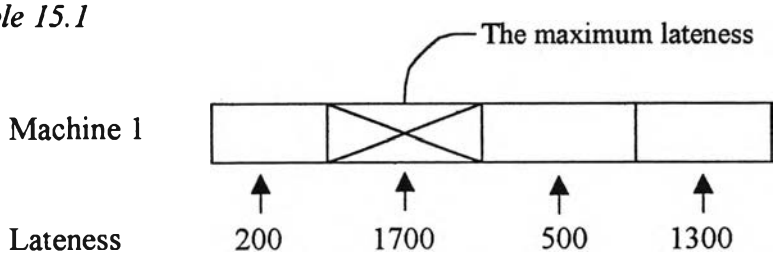
and $t_{(n+1)} = f_n$

Step 15. Calculate release time in Cut Fabric and Gas Finishing machine

Calculate the real release time in Cut Fabric Finishing machine and Gas Finishing machine:

15.1 In each machine, determine the maximum lateness order calculated in step 12

Example 15.1



15.2 Determine the release time of the maximum lateness order and use that time to calculate the release time of the previous orders and the post orders.

15.2.1 Calculate the release time of the previous orders of the maximum lateness order

15.2.1.1 Calculate the release time of the order in front of the maximum lateness order

$$t_{n_{max}-1} = t_{n_{max}} - P_{n_{max}-1}$$

15.2.1.2 Calculate the release time of the other previous orders

$$t_{n-1} = t_n - P_{n-1}$$

15.2.2 Calculate the release time of the post orders of the maximum lateness order

15.2.2.1 Calculate the release time of the order next to the maximum lateness order

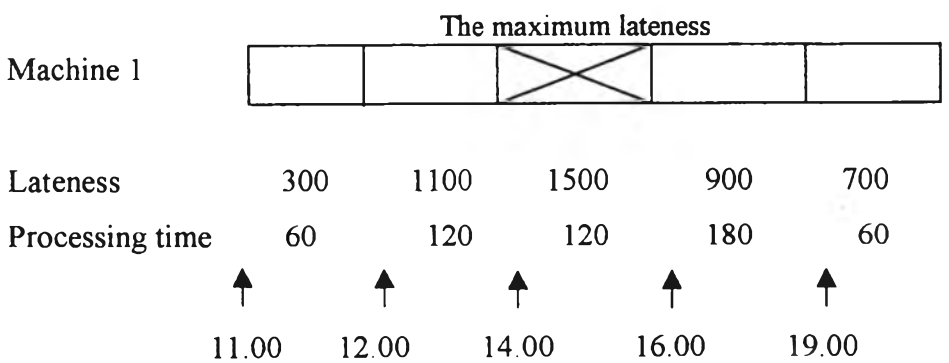
$$t_{n_{max}+1} = t_{n_{max}} + P_{n_{max}+1}$$

15.2.2.2 Calculate the release time of the other post orders

$$t_{n-1} = t_n - P_{n-1}$$

Example 15.2.2.2

The release time of the maximum lateness order is 14.00



Step 16. Schedule the orders in Steam Finishing machine

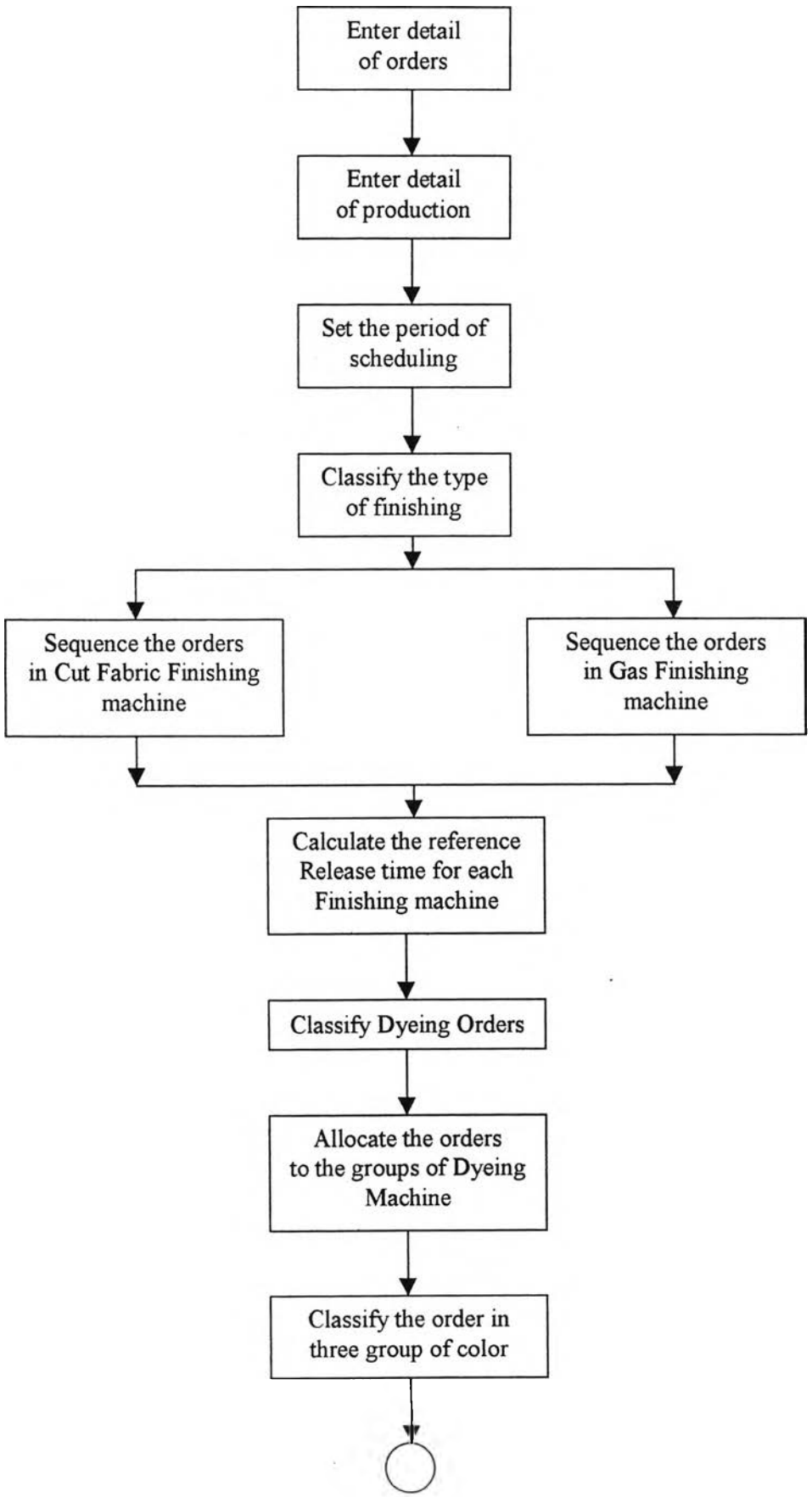
16.1 Sequence the orders in Steam Finishing machine by using FCFS heuristic.

16.2 Determine the release time of the latest order and calculate the release time of the previous orders by starting from the latest order.

$$t_{n-1} = t_n - P_{n-1}$$

Step 17. Show output of the schedule

The flow chart of developing scheduling method



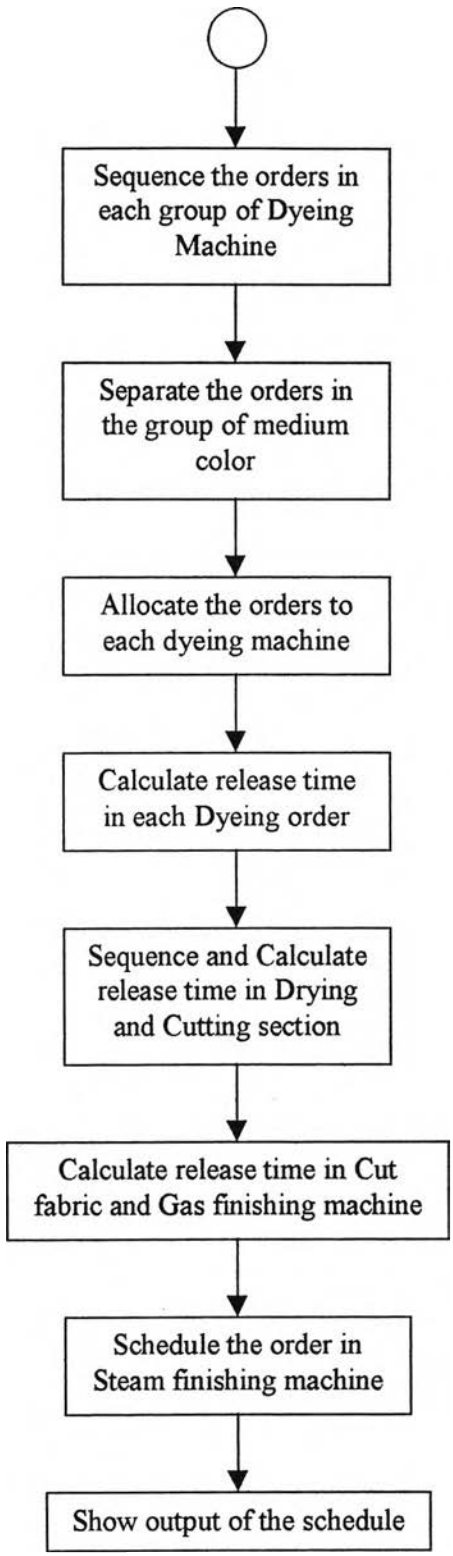


Figure 4.4.1 The flow chart of scheduling procedure

Sequence the orders in Cut Fabric Finishing Machines and Gas Finishing Machines

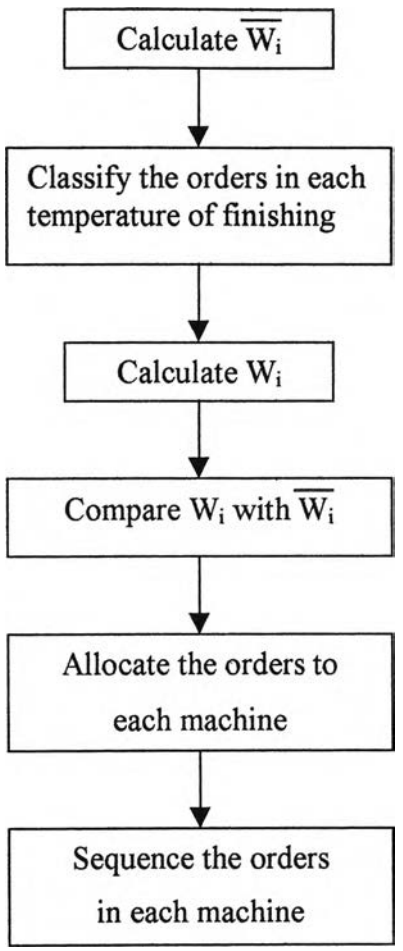


Figure4.4.2 The flow chat of sequencing the orders in Cut Fabric Finishing Machines and Gas Finishing Machines

4.5 Data Collection

To apply the developed scheduling method, a number of sets of data have been collected from the manufacturing firm to be the database of scheduling. These databases related to the input data in the work procedure step 1 & 2 to classify the suitable processing machine and calculate the production time. Thus the database can be classify in four groups.

4.5.1) The product database: This database identifies the group of machine and the condition in production in each type of fabric and each type of production. This product database consists of

4.5.1.1) The information to select the Dyeing machine

The type of fabric	The type of dyeing	The weight of fabric (kg)	The type of Machine
Poly, TK, TC, CVC, TR	Dyeing	All	HT
Cotton, Nylon	Dyeing	≤ 480	RW or W
Cotton, Nylon	Dyeing	> 480	HT
All	Off white	≤ 480	RW or W
All	Off white	> 480	HT
All	Bleaching	≤ 480	RW or W
All	Bleaching	> 480	HT
All	Scouring	All	W

Table 4.5.1.1 Database for selecting the Dyeing machine

4.5.1.2) The information to select the Finishing Machine

The type of fabric	The type of finishing	The type of Machine
All	Cut Fabric	Cut Fabric Finishing machine
All except Cotton	Uncut Fabric	Gas Finishing machine
Cotton	Uncut Fabric	Steam Finishing machine

Table 4.5.1.2 Database for selecting the Finishing machine

4.5.1.3) The Information of temperature in Uncut Fabric Finishing

Temperature	The type of fabric	The type of color
150 °C	CVC	All
	Cotton	Light and Medium
160 °C	Cotton	Dark
	TR	All
	TC	
165 °C	TK	All
	Poly	
	Nylon	

Table 4.5.1.3 Database of temperature in Uncut Fabric Finishing

4.5.2) The machine database

4.5.2.1) The information of capacity in Dyeing Machine

Machine	Range of capacity (kg)
HT 40 kg	10 – 40
HT 200 kg	60 – 210
HT 400 kg	211 – 420
HT 600 kg	421 – 630
HT 1000 kg	631 – 1050
RW 200 kg	80 – 200
RW 400 kg	201 – 480
W 40 kg	5 – 45
W 100 kg	46 – 110
W 200 kg	111 – 220
W 400 kg	221 – 440

Table 4.5.2.1 Database of capacity in Dyeing Machine

4.5.2.2) The size of width adjust equipment

Range of width (inch)	Number (Unit)
15 – 21	1
18 – 25	1
21 – 34	1
28 – 41	4
40 – 60	2

Table 4.5.2.2 Database of the size of width adjust equipment

4.5.3) The production processing time database. This data comes from the raw data in the company and the new counted time.

4.5.3.1) The processing time is dyeing

The type of fabric	The type of dyeing	Group of color	The processing time (hour/batch)
Poly, TK, TC + T	Dyeing	All	6
TC, CVC, TR	Dyeing	Light	8
		Medium	9
		Dark	11
Cotton	Dyeing	Light	5
		Medium	6
		Dark	7
Nylon	Dyeing	All	5
All	Bleaching	-	4
All	Off white	-	4
All	Scouring	-	40 min.

Table 4.5.3.1 The processing time in dyeing

4.5.3.2) The processing time in Wet fabric spinning Machine

The processing time in Wet fabric spinning machine is stable. It uses 8 minutes per time, but each time each type of fabric can be contain difference

8 minutes / time

The number of roll in each time

The type of fabric	Number of Roll
Cotton	6
TC	10
The others	8

Table4.5.3.2 The number of roll in each time of spinning

4.5.3.3) The processing time in Drying machine, Cutting machine and Finishing machine

The type of machine / The type of fabric	Cotton	TC TR TOP	Poly	Nylon	TK	CVC
Drying	12.2	7.1	9.5	7.5	7.5	10.3
Cutting	2.9	2.2	2.2	2.8	4.8	2.2
Cut Fabric Finishing	7.8	4.2	4.8	4.7	4.8	4.7
Gas Finishing	-	14.3	11.2	10.3	7.8	15.3
Steam Finishing	17.5	-	-	-	-	-

Unit: min./unit

Table 4.5.3.3 The processing time in Drying machine, Cutting machine and Finishing machine

4.5.4) The setup time database. This data also comes from the raw data in the company and the new counter time.

4.5.4.1) Setup time in Cut Fabric Finishing machine

4.5.4.1.1) Setup time in the connection between order in the different group of order

Temp	150 °C	160 °C	165 °C
150 °C	45 min.	60 min.	75 min.
160 °C	60 min.	45 min.	60 min.
165 °C	75 min.	60 min.	45 min.

Table 4.5.4.1.1 Setup time in the connection between order in the different group of order

4.5.4.1.2) Setup time in the connection between order in the same group of order is 15 minutes.

4.5.4.2) Setup time in Gas Finishing machine and Steam Finishing machine

4.5.4.2.1) Setup time in the connection between order in the different group of order is 20 minutes.

4.5.4.2.2) Setup time in the connection between order in the same group of order is 5 minutes.

4.5.4.3) Setup time in changing the width adjust equipment is 1 hour